Vol. IV, No. 4 PSYCHOLOGICAL REVIEW PUBLICATIONS AUGUST, 1921

# Journal of Experimental Psychology

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PUBLISHED BI-MONTHLY BY

PSYCHOLOGICAL REVIEW COMPANY

41 NORTH QUEEN ST., LANCASTER, PA., AND
PRINCETON, N. J.

Entered as second-class matter at the post-office at Lancaster, Pa., pending

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Lancaster, Pa., and Baltimore, Md.

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Journal of
Experimental Psychology

VOL. IV, No. 4. AUGUST, 1921

# THE LATENT TIME OF COMPENSATORY EYE-MOVEMENTS

BY RAYMOND DODGE

*Wesleyan University*

The latent time of a reaction no longer takes the pre-eminent place in psycho-physical description that it once assumed. But while we have in large measure outgrown our earlier enthusiasm for reaction-time measurements, it still remains true that no other single characteristic of a human reaction carries so many implications with respect to the probable origin and the classification of the act within the system of known psycho-physical processes as its latency. Probably also no other factor constitutes such a delicate objective control of the relative constancy of human experimental conditions. We must still measure the effects of experimental biases like drugs, habituation, fatigue, and attention largely in terms of their effects on the reaction time. It is still on the latency of a reaction that we must depend for our estimate of the degree of neural complication that is involved in its elaboration, and for our estimate of the neural level of its origin in normal life.

The relatively long latency of the saccadic eye-movements, for example, as well as the long latency of pursuit movements stamps these types of eye-movements with the character of complex reactive processes, removes them from the class of reflex responses, and places their probable origin within the superior neural systematizations.

There is no satisfactory data concerning the latency of the compensatory eye-movements. This is not explained

merely by the fact that hitherto no suitable recording device has been available. Even with our delicate mirror-recorder fully developed, the technical difficulties in recording the latent time of reaction to bodily rotation still remained almost prohibitive. These difficulties were due chiefly to the stimulus inertia. It is extremely difficult to bring the body mass into sudden motion. Moreover, it is still impossible to state the moment of acceleration when the rotation stimulus reaches super-threshold proportions. The obvious expedient under such circumstances is to produce a maximum acceleration as suddenly as possible. Unfortunately this proved not to be so desirable as it seemed. Most devices to produce sudden acceleration of large masses involve both noise and jar. In eye-reaction experiments, however, clicks, snaps, and all excessive vibration must be carefully avoided since they tend to produce lid reflexes that directly or indirectly obscure the onset of eye-movements.

Notwithstanding an intermittant experimental attack lasting many months, it is doubtful if our least objectionable onset of bodily rotation ever gave us a sharply defined moment of stimulation at all comparable to the standard reaction techniques. It may confidently be asserted that the latency of eye-reaction compensatory to bodily rotation has not yet been measured with the accuracy that characterizes our measurements of the knee-jerk, the lid-reflex, speech-reactions, or even the latency of the other eye-reaction types. Moreover, it is doubtful if a stimulation process that involves movement of the body mass can ever reach such refinement. There is, therefore, ground for supposing that the true latent time of compensatory eye-movements is less than the recorded time between the beginning of body rotation and the beginning of eye-movement. Such measurements should be regarded as approximations only. They give us the general order of the latency, not its exact measurement.

In view of the difficulties involved in starting the body-mass sufficiently quickly and silently to serve as a satisfactory stimulus moment, the idea arose of rotating the head alone. This reduces the mass moved. But we have not yet found

a technique for completely relaxing the neck muscles. There is a constant tendency to actively interfere in the process, resisting or facilitating the passive movement according to some unknown condition. The best reflex records of this sort that we have succeeded in obtaining were made by a method that we shall describe in the second part of this paper. They are best described after the technique. It is sufficient here to say that they show a reflex time in the lower part of the distribution curve of reflex measurements.

Since it is quite likely that no one who subsequently attacks the problem of recording the reflex times of compensatory eye-movements will be entirely satisfied with the method we finally adopted, an outline of promising techniques which proved unsatisfactory may prove as useful to the next experimenter as a description of the technique that we used. In that spirit we shall briefly describe the development of the rotation technique.

In recording the compensatory eye-movements of rotation it is apparently essential that the recording camera, the source of illumination, and all accessory apparatus rotate with the subject. To accommodate this paraphernalia we substituted for the customary revolving chair a small turn-table. It was mounted on a heavy tripod base which was screwed solidly to the floor.

The bearings consisted of a central shaft about 10 cm. long, accurately cupped at the bottom, resting on a small hemispherical point of hardened steel. This point carried the main gravitational thrust.* Side thrusts due to more or less inaccurate balance of the load, were taken by a ring of polished steel balls running in the customary turned grooves with screw adjustment. For studying the threshold of rotation it later seemed desirable to further diminish vibration by increasing the side thrust supports. Wire guys were consequently carried from the four corners of the turn-table to a hollow ball-bearing which was supported about three meters from the floor by struts from the wall. These three bearings constituted a remarkably smooth-running and silent system of supports, quite rigid and fairly free from vibration when the turn-table was suddenly started and stopped.

The turn-table consisted of a horizontal platform about 100 cm. by 60 cm., and about 20 cm. from the floor. On this turn-table are built as rigid and as light as practicable, a bench seat which runs lengthwise of the platform, and an apparatus table. Changes in the height of the seat are made on the primitive but effective plan of adding or withdrawing pads of paper. The apparatus table rises from one end of the platform to a height of 75 cm. It carries not only the recording camera but also the head rest, the lighting system with its resistances, and such other apparatus as the experiment required.

The recording camera consisted of the improved Dodge-Cline camera. A narrow slit in front of the sensitized paper provided for the linear orientation of simultaneous parts of the record. Time ordinates were introduced into the record by two devices. The simplest means was the periodic introduction of resistance into the lighting circuit. This produced periodic fainter spots in all the record lines, which appear in a straight line running across the record and indicate simultaneous moments of the record as well as the time. This method was used only to indicate two second intervals. The period was controlled by the seconds pendulum of an accurately running clock, acting through a relay. For more frequent time ordinates a fork-driven synchronous motor was used. This carried a perforated disk which was interposed between the camera slit and a secondary source of illumination. By this device dark line ordinates of any desired frequency could be written across the record simultaneously with the record curves.

Each reaction record comprises three record lines in addition to the time ordinates. These may be designated as follows: (1) The rotation record, a line which indicated the onset of rotation and the acceleration of the turn-table. (2) The head-line, to show how much if any of the eye-line displacement may be due to head-movement. (3) The eye-line, the main record line which must show the moment of eye-reaction and the subsequent course of the eye-movement.

## The Rotation Record

Head and eye-lines were provided for by means of the mirror-recorder which was described in the previous paper. The development of an adequate rotation record proved to be a real technical problem that delayed our reaction measurements for weeks. When it was finally solved the method seemed obvious enough. Meantime we had tried out in fact or in imagination a considerable variety of unsatisfactory devices.

We assumed that the ideal rotation record would be made by a concave mirror, like the mirror of the eye-movement recorder. Ideally this should be situated on the vertical axis of the turn-table and attached immovably to some fixed point of the environment. No support could be arranged from the top of the turn-table without interfering with the wire supports and the wires to the illumination system. This was equally and even more obviously true of supports from the sides. No support could come from the cone bearing at the bottom without destroying its delicacy. These difficulties were finally avoided by a shaft rising from an excentric axis beside the tripod support, and terminating in a cone bearing at the head rest. The shaft carried a piece of concave mirror of slightly less focal length than the recording mirrors of the eye and head, since it stood a little in front of them though in the same horizontal plane.

To yield a record of rotation it was necessary for this shaft to remain motionless while the turn-table revolved around it. This was provided for by a friction belt from a pulley on the tripod base to a pulley of the same diameter on the excentric shaft. We made this belt of electrician's tape. It is ideal for such purposes, extremely flexible, and consequently without internal friction. It can be tightly adjusted to prevent lost motion, has absolutely no slip, and operates silently. This device solved the rotation record problem perfectly. In later experiments where it became necessary to drive certain mirror and shutter devices, a chain gear drive was substituted for the tape. With more work to do the tape had a tendency to stretch.

## The Onset of Rotation

The onset of rotation of the turn-table as we have already noted was a matter of special solicitude, vital to the accurate measurement of reaction latency. Since the stimulus onset should be both rapid and silent we decided at the beginning against an electric motor drive for reaction experiments, and in favor of a spring. Heavy rubber bands proved satisfactory. They operate positively, evenly, and silently. They can be increased in number and tension to meet any requirements of force.

The real difficulty was the release of the turn-table. We were unable to devise any trigger release that was both silent and rapid acting. We tried several. Magnetic release seemed plausible. In operation, however, it could not be divorced from click and jar. The former seemed to be inherent in the demagnetization of the big core. The most satisfactory release that we achieved, *i.e.*, the quickest with the least jar and noise, was dependent on the skill of the operator rather than on a mechanical device. It worked as follows: Until the moment of release, the operator held the table still, against the tension of the springs by pulling an offset arm which was firmly attached to the table, against a fixed stop, with a padded hook. At a predetermined moment the operator shoved the hook away from him with the utmost possible suddenness. This movement did not actually rotate the table. It would have been too irregular. It merely permitted the stretched spring to exert its force against the inertia of the turn-table. It was impossible to prevent a certain amount of vibration, but with care the onset could be made noiseless, relatively vibrationless, and surprisingly uniform under constant tension of the spring. The operator's task was to get the padded hook out of the way faster than the table started to move, without hitting anything.

It was not easy to reset the springs to the same tension for different directions of rotation, and on different experimental days. We did not try for exactitude in this respect. This is a fault of the present series, though a minor one. The actual acceleration rate of each record is shown directly

in the record itself by the slant of the rotation line. In view of the method of release it did not seem advisable to try for greater refinement.

To reduce refractoriness and sensory fatigue in these experiments, the turn-table was not rotated indefinitely but was caught by the rubber springs after about 20° of rotation, gently decelerated, reversed, and finally stopped by hand.

The resulting records show that the latency of ocular compensation to rotation differs considerably from individual to individual, and apparently in the same individual according to attention, though this latter is not satisfactorily explored. The instructions were to attend to some fixed spot in space (usually some part of the room or outside landscape that seemed directly in front of the subject), to keep looking toward that spot when rotated, but without opening the eyes.

Figures 1, 2, 3, and 4, Plate I., reproduce four records of compensatory reaction. In records 1 and 2 the subject was rotated counter-clockwise, in 3 and 4 clockwise. These records should be interpreted as follows: They were taken on a falling record plate. The horizontal time ordinates progress upward, 0.01″ apart. That is, the record reads from below up. The rotation line *S* shows as a double curve that leaves the vertical slowly and passes off the record in a single uninterrupted sweep. Since the recording beam actually stands still while the turn-table revolves, the direction of rotation is always opposite to the direction of the rotation line. The eye-line *R* shows a sudden break from five to six time lines after the rotation begins, in the opposite direction to that of the rotation line.

The subsequent more or less irregular course of the eye record need not now concern us. The first significant movement is compensatory. Since both the rotation line and the eye-movement line reverse the actual direction of movement, their mutual relation is correctly represented by the records. The head-line, on the contrary, and the head-movement factor in the eye-line are recorded in their true direction. With the beginning of rotation the head line shows a slight inertia lag. The eye-reaction curve emerges sharply from

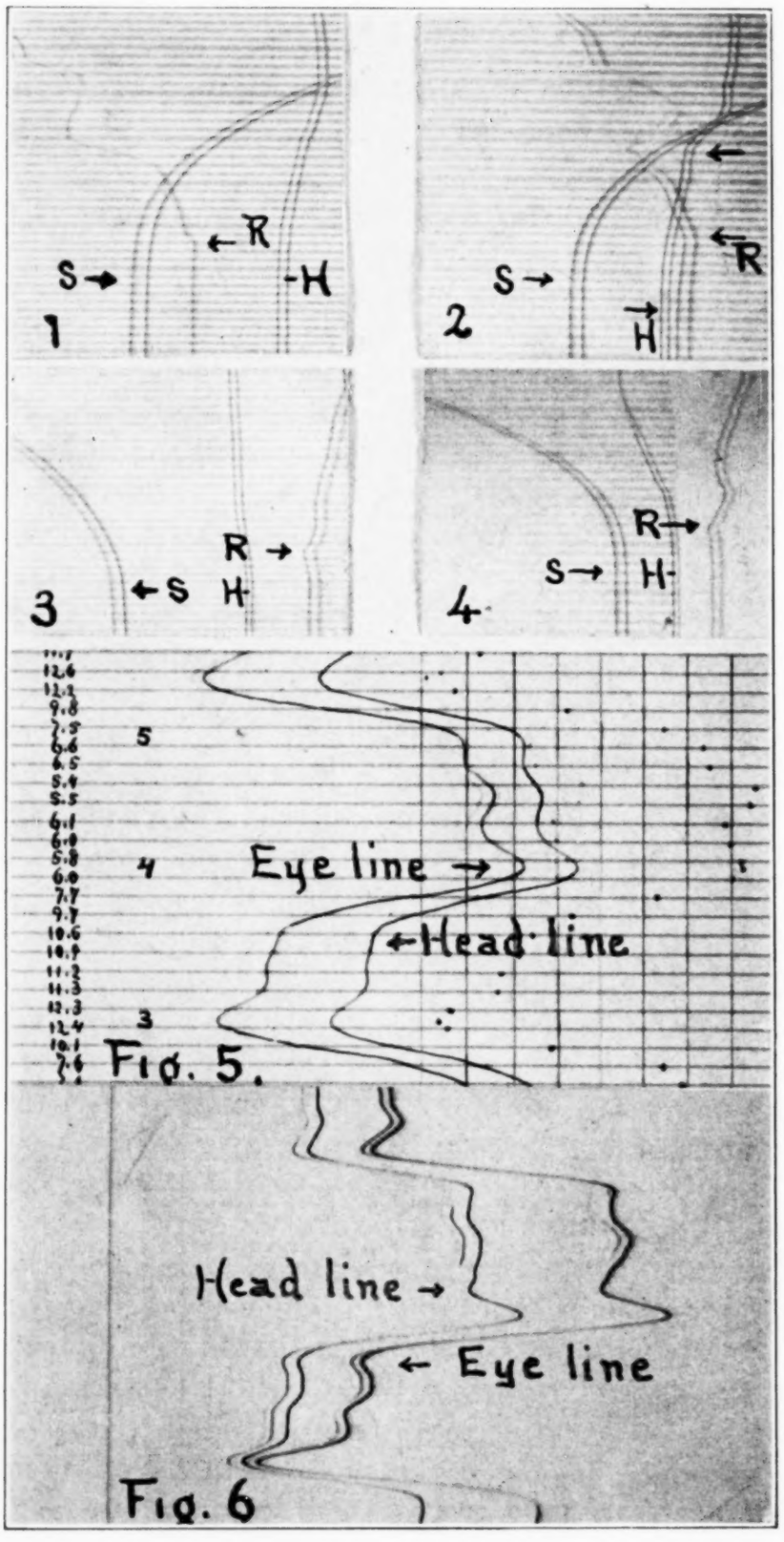


PLATE I.

FIGS. 1–4 are records of reflex compensatory eye-movements, time ordinates 0.01″ apart.

FIGS. 5–6 are records of coördinate compensatory eye-movements, time ordinates 0.05″ apart.

this phase, clearly defining the moment of reaction. It is never so easy to determine the exact moment of the beginning of rotation for reasons that we have already fully considered.

In record number 2 a notable break in both head and eye-curves may be seen about 0.09″ after the beginning of the compensatory eye-reaction. This is obviously a record of head-movement that interrupts the simple inertia drift. It is further obvious that the corresponding phase of the eye-movement curve is of greater amplitude than the head curve. The eye-movement in this case cannot be a simple translation of the eye by the head. Some sort of eye-muscle action has changed the relative position of head and eye-mirrors. This is a curious phenomenon and will further engage our attention in the second part of this paper. If we regard this eye action as some kind of compensatory reaction to a voluntary head-movement we must note a conspicuous difference between it and the reflex compensatory eye-movement which occurred 0.09″ earlier. Its latency is either zero or very close to it. We shall be able to demonstrate this peculiarity even more clearly in records that are planned to isolate it experimentally.

At the end of this head-movement episode the reflex compensation continues as though it had not been interrupted. About 0.10″ later the compensation is interrupted by an eye-movement of the first type, the rapid or saccadic type. After this the compensation curve flattens out as the oscillatory movement of the turn-table approaches its maximum amplitude and slows down, preparatory to beginning the return swing. These parts of the record are cut away to save space. The accuracy with which such changes in the direction of rotation can be followed by compensatory eye-movements together with some remarkable adaptation phenomena will be discussed in a later paper.

Returning to the latency of the compensatory movements, I have plotted all available measurements in Fig. 7. With our present technique only one record can be taken on a plate. This is not conducive to quantity production. In addition, the stimulus difficulties which we have already discussed, make the multiplication of records in the effort to establish norms, of doubtful expediency.

The measurements which we have plotted in Fig. 7 were taken from six subjects, all undergraduate students of psychology except myself. I have more legible records than any other subject. They are represented in the distribution figure by crosses. Unfortunately many of the records of the other subjects proved illegible on account of excessive head movements, lid reactions, or accidental displacement of the recording light above or below the camera slit. All legible records are represented in the figure. The units are hundredths of a second.

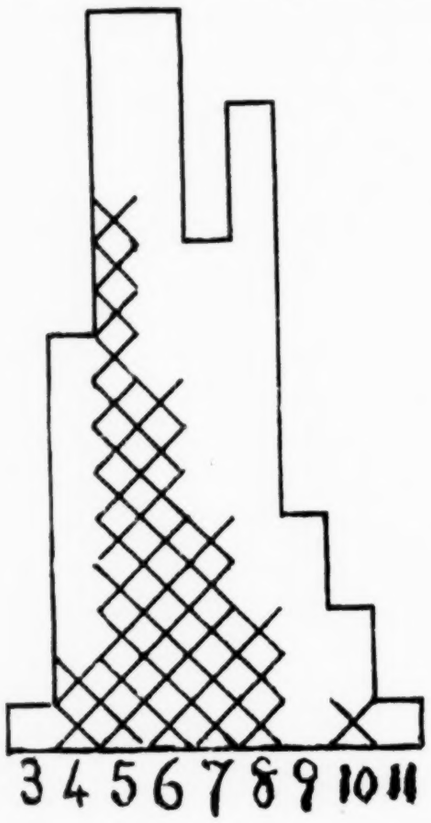


FIG. 7 is the distribution area of all available measurements of the latent time of reflex compensatory eye-movements of six subjects. The units are hundredths of a second.

There is little chance of misinterpreting these data. The mass of the measurements lie between 5 and 8 hundredths of a second. This seems to include some at present unaccountable individual differences. My own mode is 0.05". These values are clearly the latent times of sub-cortical reflexes. The latency of saccadic eye-reactions is from three to four times as long.

Without considering the pathological evidence, if we had no other data to depend on than the present records, these differences in the reaction latencies of the two phases of the compensatory process, the true compensatory and the saccadic, would indicate an essential difference of origin. This indication is borne out by evidence which will be given in a later paper, that the saccadic phase of the compensation is the more accessible to voluntary control and training.

PART II

## The Latency of the Coördinate Compensatory Eye-Movements

In record number 2, Plate I., we found indications of a different kind of compensatory eye-movement, compensatory to voluntary head-movement rather than to passive rotation. This type of eye-movement had one remarkable characteristic, distinguishing it not only from saccadic but also from the reflex compensatory eye-movements; its latent time was either zero or very close to it.

Since the eyes may remain open during these 'coördinate' compensatory eye-movements, they offer fewer technical difficulties to photographic registration than the reflex type. In my 'Five Types of Eye-movements'[1] I described a method for photographing them, together with the resulting kinetograms. Supplementary experiments by the Lamanski method which were described in the same paper proved that their continuous coördination with the head-movements to which they are compensatory, was remarkably accurate. Unfortunately the records by the technique which was then available, were not clear enough to be reproduced. So it is perhaps not surprising that notwithstanding the evidence, the existence of these remarkable eye-movements as a special type has not been generally admitted.

Our new mirror-recorder permitted us to make some extraordinarily clear records of this third type of eye-movements. The chief difficulty in photographing them is the requirement that the head be free to move. This requirement reverses the usual desideratum of a motionless head, and precludes the use of the customary head-holding devices. Nevertheless, if the recording images are to fall on the slit, some means of controlling the position of the head must be used. For the earlier records I used an optical control. For these later ones with the mirror-recorder I used a simple forehead rest. In small angular movements of the head, the loose skin of the forehead seems to furnish an ideal, almost

[1] *American Jr. of Physiol.*, 1903, 8, 307 ff.

frictionless bearing. In movements of larger amplitude we used a broad head-band around the forehead, which worked over a friction pulley behind the head.

## Theory of Coördinate Compensatory Eye-Movement Records

The chief difficulty in interpreting records of compensatory eye-movements that occur during voluntary head-movement, lies in factoring out of the curves the part that is due to head-movement and the part that is due only to eye-movement. Whenever the head rotates, the eye-globes are necessarily carried with it. If an eye were fixed rigidly in the head, the head-mirror and the eye-mirror would write parallel curves, since both would traverse equivalent arcs on concentric circles without changing their relative positions. For example, if both head and eye started at their primary positions, with the visual fixation point at an infinite distance, rotation of the head 10° to the right would carry a rigidly fixed eyeball 10° to the right as part of the head, and the line of regard would move to the right with the eye. If instead of being fixed in the head the eye were to maintain its fixation point at an infinite distance, in compensation for a head movement of 10° to the right, it must rotate 10° to the left.

On first thought this might seem to indicate that the record line of an adequately compensating eye would remain straight, whatever the angle of head-movement. This would be approximately true if the eye and the eye-mirror both rotated in the same direction with the same angular velocity. With our method of recording, the actual record is quite different. When the apex of the cornea rotates to the left, compensating for a rotation of the head to the right, a superposed mirror resting on the lid over the apex will be rotated to the right. It will regularly rotate in a direction opposite to the direction of eye-movement. That is to say, rotation of the head in any direction will cause the recording mirror of a compensating eye to rotate still farther in the same direction. A compensating eye, therefore, will write a record that is neither straight nor parallel to the record of head

movement, but a curve of greater amplitude than the head-movement curve, with homologous changes of direction.

The true compensatory component of the eye-movement curves may be found by subducting from the amplitude of the eye-movement curve the amplitude of the head-movement curve. Whenever the head- and eye-movement curves are parallel, both recording mirrors must have maintained the same relative positions. That will always indicate that the eye remained fixed in its socket. Whenever the curves cease to run parallel, there must have supervened some independent rotation of the eye-globe. If the eye-curve is of greater amplitude than the head-curve, but in the same direction, the eye-movement is compensatory. The moment when parallel curves diverge or converge is the moment of eye-reaction. The interval that elapses between the beginning of a head-movement curve and the divergence or convergence of the record-lines is the latent time of the compensatory eye-movement.

Typical compensatory eye-movement records are reproduced in Figs. 5 and 6, Plate I. In Fig. 5 the long oblique lines were too faint to reproduce and have been retouched. Measurements were taken before the record had been retouched. Fig. 6 is exactly as taken. The two records are from different subjects. One degree of head-movement displaces the head-line approximately one centimeter.

Comparison of the head- and eye-lines in Figs. 5 and 6 shows the relationship that we have just described. The eye-line follows the head-line point for point, but with increased amplitude. At no point is the head-line vertically straight. Nowhere do head- and eye-lines run parallel. This means that while the head is in continual motion, more or less rapid, the eye-compensations are equally continuous. In the attempt to express this compensation quantitatively I measured the separation of the head- and eye-lines on each time ordinate of the record from which Fig. 5 is taken. These measurements appear in the figure as a column of digits at the left. Their values are plotted in a series of dots on the right of the record. These values show a remarkably close

correlation between position of the head-line and the separation of the head- and eye-lines.

The time-interval between a change in the direction of the head curve and the divergence or convergence of the two lines would give the latent time of the compensation. Simple inspection of the curves shows that this latent time must be very short. At the end of movement 3, for example, between the preceding time-line and the apex of the curve is approximately one third of the space between time-lines. Since the time-lines in Fig. 5 are 0.05″ apart that would represent a time-interval of approximately 16 thousandths of a second. Yet in that time-interval the separation of the head- and eye-lines has measurably changed. This indicates a latency of considerably less than 0.016″. How much less cannot be estimated so easily. The facts are even more conspicuous at the end of movement 4, Fig. 5.

In some respects Fig. 6 is the best record of the phenomenon which this technique has yielded. While it unfortunately lacks legible time-lines, the speed of the record is approximately the same as that of Fig. 5. Aside from this lack the record is unusually clear. The close juxtaposition of head- and eye-lines together with the wide amplitude of the eye-movement factor favor direct interpretation from simple inspection. In this record the relative obliquity of the two lines both at the beginning and at the end of each movement is conspicuously different, apparently from the very onset of the head-movement.

While inspection of the records is sufficiently convincing to make it clear that the probable latency of the coördinate compensatory eye-movements is of a different and much smaller order of magnitude than the eye-reflexes of vestibular origin, it seemed unlikely that these differences in obliquity could be read with sufficient accuracy to prove whether the latency was ever really zero. The effort to get still more accurate records led to a substantial improvement in the technique which will presently be described.

## The Accuracy of Coördinate Compensation

In addition to indicating a very low latency these records

confirm our previous observation that the coördinate compensatory eye-movements differ from the reflex compensatory movements and from the ordinary pursuit movements in their smoothness and freedom from corrective eye-movements of the saccadic type (type 1). Such a fine coördination as is here disclosed is without a known parallel in our nervous system. If the records were not so unmistakable it would be incredible. We can understand a nervous mechanism by which the onset of a voluntary head-movement will coördinately produce an eye-movement of appropriate amplitude in the opposite direction. There are numerous familiar examples of such compensation. The coördinate compensatory movements of the limbs which are involved in maintaining equilibrium are conspicuously adequate in spite of vigorous kicking or striking. The peculiar difficulty in the present case arises from the evidence for proportional, adequate compensation for all phases of the head-movement, including the complex antagonistic process involved in stopping the rotating head-mass in a series of damped sine waves. These irregular stops can be seen in both Figs. 5 and 6.

The end of a rapid movement of finger, arm, or head is never a simple stop. The member does not reach an extreme position and stay there as one might expect it would if the contraction of a single agonistic muscle reached some arbitrary limit and held rigidly. There is always a more or less complicated rebound. Part of this rebound is doubtless a matter of momentum acting on elastic muscle tissue. There is evidence that the stop is further complicated by the interaction of antagonistic muscle groups on the basis of reciprocal innervation.[1-2] We have called attention to similar phenomena at the end of saccadic eye-movements.[3]

Whatever the cause, the fact is that no two head-movements end alike. Some show one, some two, and some three

[1] Isserlin, 'Ueber den Ablauf einfacher willkuerlicher Bewegungen,' Lpz., 1910, Engelmann.

[2] Sherrington, 'The Integrative Action of the Nervous System,' N. Y., 1906, Scribner's Sons.

[3] Dodge, 'An Experimental Study of Visual Fixation,' *Mon. Suppl. Psy. Rev.*, No. 35.

oscillations of varying extent before the head comes to rest. A nervous mechanism that is capable of producing coördinate compensation for these irregularities of stopping is quite unknown to us. That such a mechanism exists our records leave no possible doubt. If the technique for recording them could be simplified they would seem to be most favorable points of attack in the study of the effect of drugs that may be supposed to disturb coördination.

## A Skeleton Recording Camera

Our efforts to develop a technique for more adequately recording the latency of coördinate compensatory eye-movements were based on two desiderata. First, it seemed desirable to write the curves at higher speeds of the recording paper. That was merely a matter of more brilliant illumination. Secondly it seemed worth while to try to eliminate more or less completely, the head-movement factor from the eye-movement curves. Apparently this could be accomplished only by moving the record plate with the head. It proved a beautiful technical problem, and is not yet entirely solved.

The picturesque ideal would be to attach the whole recording apparatus to the beam of light from the head-mirror so that it would move exactly as the head-record moved. While this is of course impracticable, it may well function as a mental standard. It might seem at first thought that a close approximation to this ideal would be obtained by attaching the recording apparatus rigidly to the head. Such a solution would be very faulty. In the first place since the angular displacement of the recording beam from a rotating mirror is twice the angular displacement of the mirror, the record surface may not move simply with the head by any rigid attachment, but must move approximately twice as fast. Second, if the ordinary recording apparatus were attached to the head the increased inertia and momentum would render the habituated coördinations quite inadequate. One could learn little of normal motor coördinations by such an instrument. The

latter difficulty would be exaggerated by the disadvantageous leverage that must result from having the camera at sufficient distance from the head to get a reasonable amplitude of eye-movement record. Both these difficulties, however, can be met more or less satisfactorily by a suitable modification of the apparatus. The mass of the recording apparatus can be reduced to a minimum by rebuilding it in skeleton form. A system of levers can be introduced between the head and the camera to magnify the head-movement to any desired degree.

The successive refinements of apparatus as one difficulty after another was more or less satisfactorily overcome in a gradual approach towards our picturesque ideal are not germain to the present paper. In its present form the skeleton recording camera which best met the requirements may be described as a system of light levers, one end of which carries the sensitive paper. The other end terminates in a mouth-piece that is held rigidly between the teeth of the subject.

The plate-holder is reduced to a cardboard back of just sufficient size to hold the record straight by the use of paper-clips. This holder is hung on the end of a pendulum about two and one half meters long. The pendulum swings the sensitized paper behind a slit in the middle of a large opaque wooden screen 30 cm. in front of the subject.

The post from which the pendulum is suspended, rests on our oil-resistance, moving plate-holder whose various speeds provide for the successive exposure of the paper behind the slit at any desired rate. Even with a long pendulum, the angular changes in the relative position of record sheet and slit as the pendulum oscillates would vitiate the time relations of different parts of the record. That is to say, as the pendulum oscillates the time ordinates would be written at different angles. To prevent this distortion and to keep the record perpendicular to the slit at all positions of the pendulum, the pendulum-rod was doubled. The axes of the two rods were separated horizontally about 20 cm. They were held apart the same distance at the bottom by the skeleton plate-holder. The top of the record thus makes the

base of a parallelogram, and will always be parallel to the horizontal line of the axes whatever the position of the pendulum. This insures rectangular orientation of all points on the record. There remains only one distortion of the record due to the movement of the pendulum. The top of the record will be higher at either end of the swing than it is at the middle. If the pendulum is long enough this may be reduced to a negligible error. Given a pendulum that is $2\frac{1}{2}$ meters long, a total excursion of 4 cm. represents a maximum angle of 30′ with the vertical. Calculating the corresponding change in elevation by the formula $x = (1 - \cos 30')$ 250 cm. gives 0.01 cm. Even if the maximum excursion of 4 cm. took place within the time represented by two time-ordinates, *i.e.*, 0.01″, such a small change in elevation would have no measurable effect on the temporal sequence of the various record curves.

The oscillations of the pendulum and consequently of the sensitized paper were synchronized with the head by means of a system of light wooden levers that increased the angular velocity of the record by two. A light rod was held fast in the mouth of the subject by firmly setting the teeth into the yielding wood. At right angles to this mouth-rod a horizontal rod extended to the left and articulated with the middle of a short vertical lever from whose top another rod connected with the bottom of the pendulum. All connecting rods were made of very thin strips of redwood. Their bearings were thin steel V-shaped knife-edges which were held in contact by elastic rubber bands. In order to minimize distortion of the straight lines of the record as the pendulum fell behind the slit, the horizontal connecting rods were made as long as practicable, about 150 cm. The system was so light and frictionless that subjectively it seemed to have no disturbing effect on the head movements. The records showed, on the contrary, that its momentum did in fact somewhat distort the otherwise delicate compensatory eye-movements.

Figs. 8 and 9, Plate II. show two typical records. The time-ordinates are 0.01″ apart. The head-lines are almost

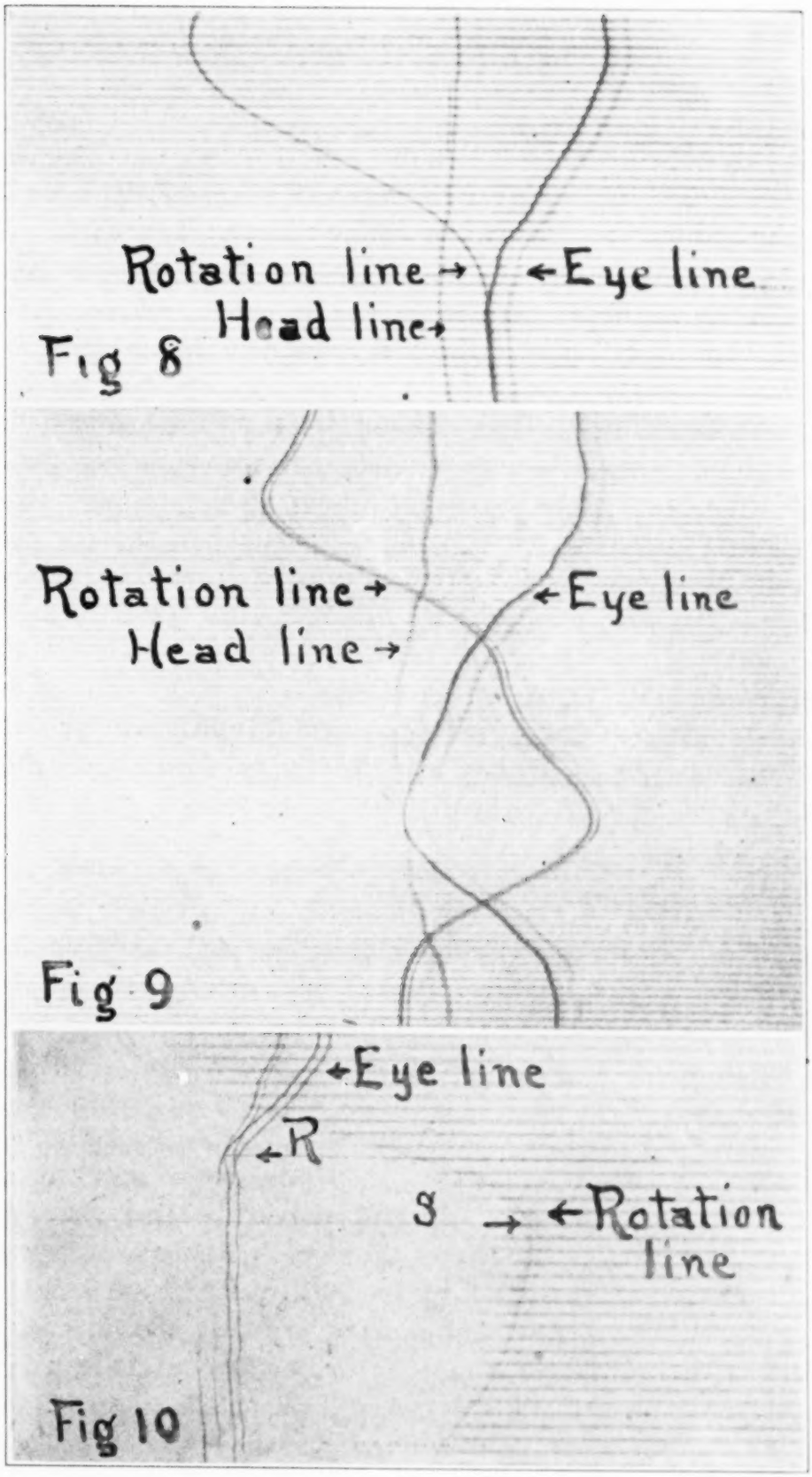


PLATE II.

FIG. 8–9 are records of coördinate compensatory eye-movements, time ordinates 0.01″ apart.

FIG. 10 is a record of the latency of a reflex compensatory eye-movement, time ordinates 0.01″ apart.

straight, fulfilling the intent of the lever system. The extent of head-movement is shown by a third line, the 'rotation line' which is traced by a motionless beam of light as the pendulum oscillates with the head. No latency within the limits of measurement is found at the beginning of head-movement in these two records. In no record was there more than 0.01″ discrepancy. In some the latency was apparently very close to 0.01″. In no case did the eyes start to move first. They commonly stopped moving before the head stopped, and regularly failed to correspond as closely with the course of the head-movement as they appear to do when the head is not loaded with the mass of the recorder.

The skeleton recorder may be said to prove our previous contention that the coördinate compensatory eye-movements may have a latency of zero. It does not fill the need of a convenient instrument for studying the accuracy of compensation under varying psycho-physical conditions. We still believe that optical means may finally be made to displace the mechanical lever system.

### Reflex Latency with the Skeleton Camera

The success of the skeleton recorder in measuring the latency of coördinate eye-movement suggested the possibility of measuring the latency of the reflex compensatory eye-movements due to vestibular stimulation, by forcibly rotating the head instead of the body mass. It was hoped in this way to produce a more sharply defined moment of stimulation. The plan worked only moderately well. It seems difficult or impossible to rotate the head of a subject by pulling on the mouth lever of the lever-system without setting the neck muscles in action. Sometimes they operate to resist the pull, sometimes to facilitate it. It proved very difficult to keep them relaxed. Whenever the neck muscles act they complicate the record with coördinate compensatory eye-movements. Furthermore, it proved difficult to hold the head steady before moving it, and to move it suddenly without jar. The best head rotation stimulus that we produced was by the aid of an elastic rubber device, analogous to that which we found most satisfactory in moving the turn-table.

Two rubber bands were attached to the mouth-piece lever and stretched in opposite directions so as to hold it in an elastic equilibrium. No simple disturbance of that equilibrium by a push or pull proved at all satisfactory. Releasing one of the springs by a trigger device produced a decided snap and consequent lid reflex. Some excellent records were obtained by displacing the elastic equilibrium to one side or the other relatively slowly and then suddenly withdrawing the pressure. The elastic that was most stretched then became the motive force for rotating the head in the direction of the elastic equilibrium. It operated suddenly, evenly, and silently.

A record which was obtained by this procedure is reproduced in Fig. 10, Plate II. We believe that this record represents the best available reaction technique for measuring the latency of the eye-reactions to vestibular stimulation. In this record the latency is exactly 0.05″. It falls in the lower part of the distribution of latency measurements, but in the mode of the measurements for R.D. (See Figure 7.)

As a result of these records we may make a critical comparison of the two types of compensatory eye-movement with the pursuit eye-movements.

1. With respect to origin: The stimulus to ocular pursuit-movement is visual and consists of real or apparent motion of the object of regard. The stimulus for reflex compensatory movements is rotation. Its receptor field centers in the vestibule. Whether other origins of the perception of rotation can produce compensatory eye-movements has never been proved, though it is a question of great theoretical and practical importance. The stimulus for coördinate compensatory movements is central. In our present ignorance of the mechanism it may be hypothetically pictured as a collateral impulse of the same origin as the impulse that moves the head.

2. With respect to latency: The pursuit movements regularly begin after a natural reaction time of the order of 0.2″. It may be considerably reduced by practice and a limitation of the range of possible directions of motion. The

reflex compensatory movements have a latency of the order of 0.05″. The coördinate compensatory movements may have a latency of zero, but faults of coördination up to 0.01″ appear in our records.

3. With respect to onset: The pursuit movement begins with a series of inaccurate approximations to adequate pursuit, interrupted by saccadic movements either in the same or opposite direction, usually the former. Only after practice does the pursuit movement become an adequate, smooth pursuit. On the basis of 'short-lived motor habits,' when adequate pursuit of a pendulum is once originated, it tends to persist within the limits of fatigue, with only small and infrequent corrective movements. Persistent pursuit in one direction is rhythmically interrupted by saccadic movements that bring the eye back to approximately its primary position. This produces a kind of nystagmoid-motion that cannot be objectively distinguished in the records from the reflex nystagmus of rotation. Reflex compensation shows less hesitation in its onset. Since there is apparently no subjective criterion of adequacy when the eyes are closed, the greatest variety of compensation speeds may result from the same rotation stimulus. Whether or not compensation can be eliminated by practice, whether it is ever adequate are still open questions. It is regularly interrupted under normal circumstances, like the pursuit movements, by saccadic returns to approximately the primary position of the eyes, giving rise to the phenomenon of reflex ocular nystagmus as we may call it to distinguish it from the nystagmus of pursuit. Unlike both the other eye-movements, coördinate compensation movements are astonishingly smooth. They are never interrupted, under normal circumstances, by corrective movements except as the point of fixation is voluntarily changed. For moderate amplitudes of head-movement and moderate velocities, coördinate compensatory eye-movements are amazingly accurate.

4. Interaction of the various types: When the eyes are open during passive rotation of the head, pursuit must coöperate with reflex compensation, for clear vision of the

environment. We have no knowledge of how the coöperation is effected. Similar coöperation will doubtless obtain between pursuit and coördinate compensation. Voluntary rotation of the head which conditions coördinate movement of the eyes must also act as stimulus for reflex compensation. In our records there is no indication of the latter type interplaying with the former. One might expect a reaction phenomenon at the end of the normal reflex latent time, but no such disturbance of the smooth coördinate compensation has been found.

In some of these combinations the factors may on occasion conflict. There are various indications that such conflicting tendencies are a source of discomfort. As to which tendencies win out in such conflicts, and what the characteristics of the resulting eye-movements would be, we are profoundly ignorant except in one case, namely, when the stimulus of decelerated rotation conflicts with the visual tendency to fixation, as in after-nystagmus.

Many of the characteristics of the reflex compensatory eye-movements are also still in doubt. We know neither how adequate the compensation may be, nor how the adequacy may be affected by training. In the case of coördinate compensation there must be differences due to changes in accommodation for distance, as well as for various head-loads. The mechanism of these adaptations is an unexplored field.

# AN EXPERIMENTAL STUDY OF ASSOCIATIVE INHIBITION[1]

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## INTRODUCTION

The several laws of inhibition of the higher mental processes, referred to as associative, retroactive, terminal, etc., have been derived and demonstrated, in part, by the use of nonsense syllables. The laws formulated from such studies, useful as they may be for pure science, are made to appear much simpler and less involved than they doubtless are in meaningful associations.

The law of associative inhibition, first expressed by Müller and Schumann, (8) asserts that the bond of connection between any two cognitive elements tends to inhibit the formation of a similar bond between either and a third element, or "If *a* is already connected with *b*, then it is difficult to connect it with *k*; *b* gets in the way."

A number of studies on the interrelation of growing habits more or less opposed to each other tend to show that they become mutually inhibitive, only under certain conditions. Bair (1) has shown that the interference of two opposing habits formed during the acquisition of skillful movements grow less the more automatic the two responses become, and that "finally, after both sets of reactions were practiced to perfection, the interference disappeared." Culler (4) in his study on 'Interference and Adaptability' points out that "when two opposing associations, each of which excludes the other, are alternately practiced with one, four, or eight repetitions of each association before the other is resumed, the opposing associations have an interference effect upon each other, in

[1] This study was made possible through a fellowship by courtesy granted to the writer by The Johns Hopkins University for the academic year 1919 and 1920, and for which I hereby make grateful acknowledgment.

all" (subjects). The interference effect grows less and less, while the practice effect becomes greater so that either of them can be called up independently without the appearance of the other." Kline and Owens (7) in their study, 'Learning Skillful Movements,' found that many errors of the second series were the correct distributions of the first. Such errors were most likely to occur when the speed was forced beyond the power of the delivering habit. Brown, as quoted by Swift (13), found in an experiment of sorting cards that changing the methods of sorting increased errors and checked speed, but 'that as the work proceeded practice in one order helped in learning the other.'

These experiments are cited here because they emphasize two points: (1) That the amount of inhibition mutually exerted by two opposing movements depends upon the degree of automatism possessed by each, (2) that two opposing movements when highly automatized, may facilitate, rather than inhibit each other. The operation of such laws in more or less opposing skillful movements raises the question if some such condition may not obtain in associative mechanisms involving only central factors, so-called.

May not different degrees of strength in the association bonds of central mechanisms produce decided variations in their inhibiting and facilitating relations? May not the associations involving meaningful material and functioning in daily life conform to other laws than those obtaining in the association bonds for nonsense material?

The present investigation was made to determine what variations, if any, exist in the law when meaningful associations formed in daily life are involved.

## Material

Meaningful material conformable to the Müller-Schumann formula must have two terms whose associative bonds are formed by daily experience and the second pair of terms between which associative bonds are *to be* formed must have one term that occurs in the first pair and the other, similar in nature to the second of the first pair, must be void of

associations with either term of the first pair. A State of the Union and its capital, *e.g.*, Tennessee-Nashville, matches fairly well the first pair of terms *a* associated with *b*. But if it be attempted to associate a false capital with the state, the condition of *a* associated with *k* is set up, *e.g.*, Tennessee-Sacramento. Two groups of 15 states, each so chosen as to represent all sections of the Union were formed and given false capitals.

The results derived from the use of states and false capitals called for the use of meaningful material derived from other sources to serve both as a check and as a means for following up certain clues bearing on what appeared to be new aspects of associative inhibitions. Two lines of material were selected for this purpose, numbers and false sums—$6 + 4 = 11$—and literary works and false authors. For a check on the association between states and false capitals, entirely unknown counties and county seats were used; for a check on numbers and false sums, the addition of two letters and their sums as $d + h = 17$ were used, while unknown works of literature coupled with their true authors were compared with the literary works and their false authors. The Johns Hopkins chronoscope was used to measure the association time of individual subjects and the stop watch to measure time in the group tests.

## Procedure

The material, when arranged in convenient series for learning, was presented to the subjects in groups and as individuals. The method of work with the groups is reported first.

### *A. Procedure with Groups*

College students, men and women, were subjects. They were first asked to write the names of states with which they were familiar (familiar being defined as knowing something of the history, industry and geography of a state, and, in addition, it may mean personal associations of one sort or another). It was found that 58 percent of the capitals known by the men were those of 'familiar' states, and 54 percent of the capitals known by the women were of 'familiar' states.

So, being familiar with a state was by no means a guarantee that its capital would be known, although the condition is some better than fifty-fifty. The 'current knowledge' of the capitals of the fifteen states used in the investigation was ascertained by having each student write from memory the capitals in blank spaces opposite their respective states. (By 'current knowledge' is meant knowing the correct capital of a state on the instant and without previous warning as to the question.) To insure that the student associated the true capital with its state *at least once*, both state and capital were recorded by the student from dictation. See Table I.

## TABLE I

CURRENT KNOWLEDGE OF STATES AND CAPITALS—COLLEGE STUDENTS

| Familiar States | | | | True Capitals Known: 15 States | | | |
|---|---|---|---|---|---|---|---|
| Men | | Women | | Men | | Women | |
| Frequencies | States | Frequencies | States | Frequencies | Capitals | Frequencies | Capitals |
| 1 | 1 | 1 | 0 | 1 | 0 | 4 | 0 |
| 1 | 2 | 1 | 1 | 5 | 1 | 11 | 1 |
| 6 | 3 | 4 | 2 | 8 | 2 | 15 | 2 |
| 5 | 4 | 10 | 3 | 9 | 3 | 14 | 3 |
| 3 | 5 | 13 | 4 | 6 | 4 | 20 | 4 |
| 8 | 6 | 9 | 5 | 3 | 6 | 12 | 5 |
| 6 | 7 | 9 | 6 | 2 | 7 | 6 | 6 |
| 3 | 8 | 16 | 7 | 4 | 8 | 9 | 7 |
| 2 | 9 | 10 | 8 | 3 | 9 | 3 | 8 |
| 1 | 10 | 5 | 9 | 2 | 10 | 3 | 9 |
| 1 | 11 | 6 | 10 | 2 | 11 | 1 | 10 |
| 2 | 12 | 3 | 11 | 1 | 14 | 2 | 11 |
| 5 | 13 | 3 | 12 | | | | |
| 1 | 16 | 2 | 14 | | | | |
| | | 3 | 15 | | | | |
| | | 2 | 16 | | | | |
| | | 2 | 16 | | | | |
| | | 2 | 17 | | | | |
| | | 1 | 19 | | | | |
| Totals.....45 | 314 | 100 | 714 | 46 | 219 | 100 | 405 |
| Mean..... | 6.97 | | 7.14 | | 4.54 | | 4.05 |
| Mode..... | 6 | | 7 | | 3 | | 4 |
| Mdn..... | 5.8 | | 6.16 | | | | 4.3 |

Read first line thus: One man was familiar with only one state, one woman with no states; one man knew no state capital, four women knew no state capital, etc.

After having secured the data for 'familiar' states and for 'current knowledge,' the learning series (Ser. 1, Group *a*) composed of fifteen states and false capitals, arranged in parallel columns, was presented. The subjects were instructed to associate each false capital with the state on the same line and to learn the two so as to be able to recall the capital if required. The subjects were not told the time allowed for learning the series—fifteen minutes—but that they would be expected to recall them in some form. Subsequent work showed ten minutes to be a better duration for learning a false series.

1. *Immediate Recall.*—All responses of whatever sort throughout the work began and stopped at prearranged signals. Immediate recall was made by writing names of false capitals opposite their respective states in a different order as given in Series I., Group *b*. Time for recall 1′ and 30″.

SERIES I., GROUP *a*
*Arranged for Learning*

| State | Capital |
|---|---|
| Florida | Columbus |
| Delaware | Providence |
| Michigan | Boston |
| Washington | Austin |
| Wyoming | Augusta |
| Iowa | Nashville |
| Vermont | Columbia |
| Texas | Des Moines |
| Connecticut | Trenton |
| Pennsylvania | Atlanta |
| Colorado | Albany |
| Maine | Cheyenne |
| Arkansas | Bismarck |
| Illinois | Raleigh |
| Alabama | Phoenix |

SERIES I., GROUP *b*
*Arranged for Immediate Recall*

| State | Capital |
|---|---|
| Arkansas | _____ |
| Michigan | _____ |
| Wyoming | _____ |
| Iowa | _____ |
| Texas | _____ |
| Connecticut | _____ |
| Maine | _____ |
| Alabama | _____ |
| Vermont | _____ |
| Illinois | _____ |
| Delaware | _____ |
| Colorado | _____ |
| Pennsylvania | _____ |
| Florida | _____ |
| Washington | _____ |

2. *Recognition of False Capital.*—After an interval of 48 hours, the same list of states arranged in a new order was again presented for the purpose of recognizing the false capitals. Each false capital was placed opposite its state, along with the names of three or four other large cities. Sample lines are here given.

SERIES I., GROUP *c*

Strike out with a cross mark thus, ×, the false capital that you have just learned. Make no other marks.

| State | Capital |
|---|---|
| Washington | San Diego, Toledo, Austin, Wheeling, Kansas City |
| Pennsylvania | Atlanta, Richmond, Pittsburgh, Omaha, Lowell |
| Florida | Miami, Columbus, Springfield, Dayton, Leavenworth |

Sixty seconds were allowed for recognition. The fact of recognition was shown by the subject striking out false capitals.

3. *Delayed Recall.*—The college women made a delayed recall of false capitals after an interval of seven days, recalling 43 percent; the college men made a recall after twenty-seven days, recalling 18 percent. This long interval was from necessity rather than choice.

The names of fifteen counties and their respective county seats were presented, learned, recalled, and recognized under conditions similar to those given above. Table II. shows the number of subjects in each series.

## TABLE II

SHOWING RESULTS OF IMMEDIATE RECALL OF FALSE STATE CAPITALS AND OF TRUE COUNTY SEATS (15 IN EACH SERIES)

| 15 in Each Series | Men | | Women | |
|---|---|---|---|---|
| | False Capitals | County Seats | False Capitals | County Seats |
| No. of Subjects | 46 | 41 | 100 | 99 |
| Total Number Recalled | 464 | 466 | 830 | 12.73 |
| Mean | 10.87 | 11.36 | 8.30 | 12.85 |
| Median | 10 | 12 | 8 | 14 |
| P.E. of Median | 1.230 | 0.901 | 0.772 | 0.613 |
| Percentages | 67.20 | 75.70 | 55.30 | 85.00 |

This should be read: In a series of 15 false capitals 46 subjects recalled 464, or 67.2 percent.

SERIES I., GROUP *d*, OF COUNTIES LEARNING SERIES

| County | County Seat | County | County Seat | County | County Seat |
|---|---|---|---|---|---|
| Quitman | Belain | Pike | Magnolia | Alcorn | Corinth |
| Leflore | Greenwood | Hinds | Raymond | Benton | Ashland |
| Barbour | Clayton | Pearl | Poplarville | Wilcox | Camden |
| Copiah | Hazelhurst | Tate | Senatobia | Homes | Lexington |
| Tippah | Ripley | Sharkey | Rolling-Fork | Webster | Walthall |

The results of these three forms of response to false capitals: immediate recall, recognition, and delayed recall, are shown in Table III. They indicate that states whose true capitals were known offered apparently less inhibition than states having capitals unknown to the subjects, that is, unknown at the time under the conditions of the test. Or, in terms of inhibition, a state whose capital is known offers less resistance to being associated with a false capital than a state whose capital is unknown. Table III. shows that the ratio of false unrecalled capitals to known state capitals is, for each of the three forms of response, less than the ratio of false unrecalled to unknown state capitals.

TABLE III

RESULTS OF INHIBITING EFFECTS OF KNOWN AND UNKNOWN STATE CAPITALS ON LEARNING FALSE STATE CAPITALS (15 CAPITALS IN A SERIES)

*College Men*

| No. of Students | Nature of Response | True Capital | False Capital | Ratio of False Unrecalled to Known and Unknown True Capitals |
|---|---|---|---|---|
| 46..... | Immediate | Known 218 | Unrecalled 52 | 0.2385 |
| 46..... | Recall | Unknown 472 | Unrecalled 165 | 0.3491 |
| 46..... | Recognition | Known 218 | Unrecognized 10 | 0.0458 |
| 46..... | | Unknown 472 | Unrecognized 56 | 0.1144 |
| 38..... | Delayed Recall | Known 180 | Unrecalled 128 | 0.7111 |
| 38..... | Delayed Recall | Unknown 350 | Unrecalled 339 | 0.9685 |

*College Women*

| No. of Students | Nature of Response | True Capital | False Capital | Ratio of False Unrecalled to Known and Unknown True Capitals |
|---|---|---|---|---|
| 100..... | Immediate | Known 405 | Unrecalled 160 | 0.3950 |
| 100..... | Recall | Unknown 1095 | Unrecalled 502 | 0.4584 |
| 93..... | Recognition | Known 335 | Unrecognized 10 | 0.2985 |
| 93..... | | Unknown 967 | Unrecognized 44 | 0.4550 |
| 93..... | Delayed Recall | Known 372 | Unrecalled 192 | 0.5161 |
| 93..... | Delayed Recall | Unknown 1023 | Unrecalled 599 | 0.5855 |

Further investigation was suggested by these results, using association material in which the strength of the bond of

connection could be roughly determined *in advance* of the experiment. For such material the field of literature was chosen. Three lists of literary works and their authors, 'well-known,' 'less known,' and 'unknown,' were prepared and varied until satisfactory. The different degrees of familiarity were determined by submitting the lists, composed of twenty or more literary works, individually, to a number of educated persons. They rarely failed to give an author of the supposed well-known list. Several authors of the less known list could not be recalled, or were known to only a few, others were doubtful. Two of the individuals had never connected Edwin Markham with The Man With the Hoe, or Browning with The Ring and the Book. The third list played its part perfectly as 'unknown literature.' The two lists of 15 literary works and their false authors, chosen from this preliminary survey, are here submitted.

| Well-known Literature | False Authors | Less Known Literature | False Authors |
|---|---|---|---|
| The Raven | Darwin | Modern Painters | Dante |
| Les Miserables | Shakespeare | The Ring and the Book | Irving |
| David Copperfield | Longfellow | Sleepy Hollow | Stowe |
| Gulliver's Travels | Dickens | She Stoops to Conquer | Ruskin |
| Faust | Homer | Tam O'Shanter | Huxley |
| Origin of Species | Stevenson | Vanity Fair | Emerson |
| Paradise Lost | George Eliot | The Man with the Hoe | Kipling |
| Pilgrim's Progress | Hawthorne | Vision of Sir Launfal | Whitman |
| Treasure Island | Milton | Uncle Tom's Cabin | Holmes |
| Ancient Mariner | Bunyan | The Scarlet Letter | Markham |
| The Lady of the Lake | Whittier | The Jungle Book | Prescott |
| Hamlet | Poe | Rasselas | Lowell |
| Hiawatha | Coleridge | The Inferno | Thackeray |
| The Iliad | Goethe | The Skylark | Browning |
| Snow Bound | Tennyson | The Excursion | Sheridan |

(In using this literature with large groups, it soon appeared that the degree of familiarity, or difficulty, should have been determined in a preliminary test on a much larger number of subjects not to be used in the experiment proper, of course, and the results arranged in array for purposes of selection. But the present arrangement, while not the best, served the end of this investigation.)

The literature and authors were used, in the main, like the states and capitals. First: The degree of familiarity with the fifteen authors of well-known literature was deter-

mined. Second: Fifteen false authors were associated with the well-known literature. Here the learning time was ten minutes. Third: Immediate recall, time 1′ 45″. Fourth: Delayed recall was made 48 hours later, time 1′ 45″. The 'less known' literature was presented and treated similarly. The recognition test (Otis method) was not used with the literature series. The 'unknown literature' was treated as the other two, with the exception of the familiarity test. Table IV. shows the number of subjects used. The university students were all men, the state normal school students were women and men, the latter composing about 6 percent.

## TABLE IV

SHOWING CURRENT KNOWLEDGE, LEARNING OF FALSE AUTHORS, AND TRUE AUTHORS OF UNKNOWN LITERATURE (15 in Series)

| Class of Literature | Class and No.[1] of Students | Nature of Response | Total Known | Mean | Median | Mode | Percentage |
|---|---|---|---|---|---|---|---|
| True Authors of Well Known Lit. | University[2] . 36 | Remembering | 390 | 10.8 | 11.5 | 13 | 72.20 |
| | State Normal School....163 | Rememberng | 1,495 | 9.17 | 10.0 | 11 | 66.58 |
| Less Known Lit. | University . .38 | Remembering | 216 | 5.60 | 5.9 | 7 | 37.80 |
| | S. N. S.....139 | Remembering | 693 | 4.92 | 4.0 | 4 | 33.22 |
| Unknown Literature..... | University . .38 | Immediate Recall | 436 | 11.50 | 15 | 15 | 76.50 |
| | S. N. S.....178 | Immediate Recall | 2,323 | 13.00 | 14 | 15 | 87.00 |
| False Authors of Well Known Lit. | University . .36 | Immediate Recall | 391 | 10.86 | 12 | 15 | 72.40 |
| | S. N. S.....163 | Immediate Recall | 1,869 | 11.46 | 13 | 15 | 83.25 |
| Less Known..... | University . .38 | Immediate Recall | 515 | 13.55 | 15 | 15 | 90.35 |
| | S. N. S.....139 | Immediate Recall | 1,591 | 11.44 | 13 | 15 | 76.30 |
| Well Known Lit. | University . .35 | Delayed Recall | 258 | 7.37 | 7 | 8 | 49.14 |
| | S. N. S.....149 | Delayed Recall | 1,180 | 7.90 | 7 | 7 | 52.79 |
| Less Known..... | University . .34 | Delayed Recall | 226 | 6.35 | 6 | 5 | 44.31 |
| | S. N. S.....120 | Delayed Recall | 578 | 4.80 | 4 | 5 | 32.10 |
| True Authors Unknown Lit... | University . .38 | Delayed Recall | 387 | 10.1 | 11 | 11 | 67.8 |
| | S. N. S.....127 | Delayed Recall | 835 | 6.5 | 6 | 4 | 43.7 |

[1] Difference in number of students was due to absences from class.
[2] There were no college women in this part.

## Results of Group Tests

Inspection of Table I. shows the number of states considered 'familiar' by 45 college men and 100 college women. The alleged larger number of familiar states on the part of the women does not check with their current, or actual knowledge of state capitals. The college men show a 'current' knowledge of 30 percent and the college women of 27 percent of state capitals, both somewhat below our expectations.

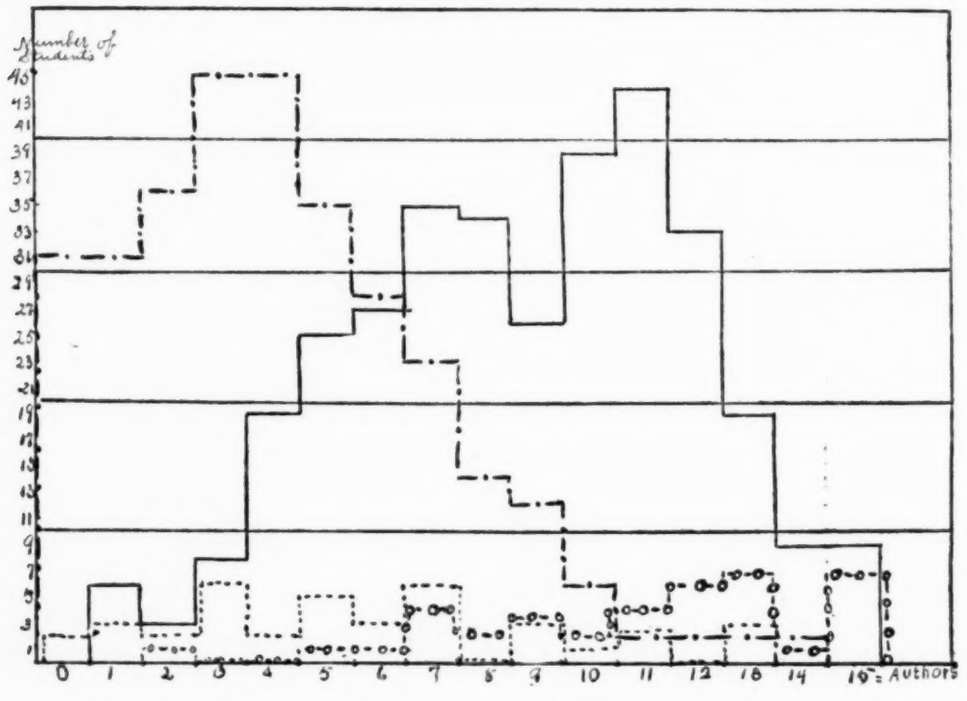
But even with this comparatively small strength of bond between state and capital, it appears to have offered opposition to learning false capitals. The difference between the amount of learning of false capitals and of county seats shows this unmistakably. With the men, the difference is 8.5 percent and for the women 29.7 percent or an average of 19.1 percent in favor of the county seats.

But these are gross results derived from the responses of groups, and as such they fail to show whether the opposition to the false capital was offered by well-known, or less known, or barely known, or by capitals at the guessing stage of 'current' knowledge. Relying upon, as well as applying, the law of associative inhibition, one should claim that the well-known capitals offered the opposition. There is one way open, however, by which we may settle whether it is the well-known or the unknown capitals that exert the greater inhibition. From the data of current knowledge of capitals, two lists were derived, *known* and *unknown*, and it was quite possible to ascertain on a basis of ratios the relative opposition produced by the two sets of capitals. The ratio of the number of unrecalled false capitals to the number of states whose true capitals were known was computed, and, likewise, the ratio of the number of unrecalled false capitals to the number of states whose true capitals were unknown was reckoned. The ratios were computed alike for immediate and delayed recall and for recognition. For each form of response it was found that the ratio of the unlearned false to the known true capitals was less than the ratio of the unlearned false to the unknown true capitals. Table III. shows

the numerical results from which the ratios were computed. They are expressed decimally.

So far as these facts go, they show that relatively strong associations between two mental elements offers less inhibition to the formation of a bond between either of the two and a third element, than a weaker bond between two such elements; and also that associations are more easily established between two equally new cognitive experiences than between old experiences void of prior connection with each other. The results of the check series, composed of county seats, referred to above, show this also.

GRAPH I, showing the frequency distribution of scores made by State Normal and University students in naming the authors of well-known and of less known literature.




| Students | Number | Literature | Key to Graph |
|---|---|---|---|
| State Normal | 336 | Well-known | = ——— |
| State Normal | 314 | Less Known | = — - — - — - — |
| University | 37 | Well-known | = — o — o — o — |
| University | 38 | Less Known | = - - - - - - - - - - - - - |

As already indicated, the capitals classed here as 'unknown' must be, for the most part, *apparently*, and not actually, unknown. It is better to assume that the unknown

is the *less known* capital, and that as such it offers greater inhibition to learning false capitals than the assumed well known.

The use of literature and authors enables one to pass from assumptions to positive knowledge about the learning material. When *well-known* literature was presented to 199 of the 374 subjects under test conditions, 63 percent of correct authors were named, while 177 of the same subjects under like conditions gave 34 percent of correct authors of less known literature. Diagram I. shows in graphic form the difference in degree of familiarity between the two types of literature. Table IV. shows the number and type of students and the mean, median, and mode, of each type in learning the three kinds of literature. The university students were juniors, the state normal students were juniors and seniors, about 80 percent the latter. These two distinct groups of students, working in quite different institutions, show a surprising uniformity of results. Their medians and modes very often agree and the differences are slight, their means differing only by one or two authors, and in one case only, by as much as 3.6, that occurring in unknown literature. Their respective percentages show differences ranging from 3.65 percent in the case of 'delayed recall' for false authors of well-known literature, to 14 percent occurring in 'immediate recall' of false authors in less known literature. This degree of uniformity of results seemed to justify combining them in Tables VI. and VII. It was found in the case of W.K. Lit. that the ratios of the unrecalled false to the respective known and unknown authors bore to each other the same relation as the similar ratios in the study with capitals, but in the L.K. Lit. the same ratios are reversed with but one exception, *viz.*, in immediate recall of false authors of L.K. Lit. by state normal students. Considering Table V., the results of the university students show a decided reversal in both immediate and in delayed recall of L.K. Lit. The ratios are, .1250 and .0762 in immediate recall, and .5797 and .3571 in delayed recall. That is, when a true author was known in L.K. Lit. greater inhibition was produced than if the true author had

## TABLE V

INHIBITIONS OF FALSE AUTHORS IN LITERATURE

*S. N. S. Students*

Fifteen Well-known Authors

| Nature of Response | Number Students | True Authors | | False Authors Unrecalled | Ratios Known and Unknown True Authors to Unrecalled False Authors |
|---|---|---|---|---|---|
| Immediate recall..... | 163 | Known | 1,495 | 304 | .2073 |
| | 163 | Unknown | 950 | 225 | .2368 |
| Delayed recall..... | 148 | Known | 1,375 | 590 | .4290 |
| | 148 | Unknown | 860 | 424 | .4930 |

*J. H. U. Students*

| | | | | | |
|---|---|---|---|---|---|
| Immediate recall..... | 36 | Known | 390 | 47 | .1250 |
| | 36 | Unknown | 150 | 100 | .6666 |
| Delayed recall..... | 35 | Known | 377 | 176 | .4668 |
| | 35 | Unknown | 148 | 90 | .6081 |

*S. N. S. Students*

Fifteen Less Known Authors

| Nature of Response | Number Students | True Authors | | False Authors Unrecalled | Ratios Known and Unknown True Authors to Unrecalled False Authors |
|---|---|---|---|---|---|
| Immediate recall..... | 139 | Known | 693 | 150 | .2164 |
| | 139 | Unknown | 1,392 | 323 | .2327 |
| Delayed recall..... | 124 | Known | 593 | 356 | .6003 |
| | 124 | Unknown | 1,267 | 588 | .4561 |

*J. H. U. Students*

| | | | | | |
|---|---|---|---|---|---|
| Immediate recall..... | 38 | Known | 216 | 27 | .1250 |
| | 38 | Unknown | 354 | 27 | .0762 |
| Delayed recall..... | 34 | Known | 188 | 109 | .5797 |
| | 34 | Unknown | 322 | 115 | .3571 |

been unknown. The same thing was true of the normal school students in delayed recall. The less known authors

# TABLE VI

## INHIBITIONS TO FALSE AUTHORS IN WELL-KNOWN LITERATURE

| Books | Total Known | | I. Immediate Recall (199 Subjects) Unrecalled *False* Authors, when *True* Authors are: | | | | Total Known Number | II. Delayed Recall (183 Subjects) Unrecalled *False* Authors, when *True* Authors are: | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *a.* Known | | *b.* Unknown | | | *a.* Known | | *b.* Unknown | |
| | No. | Percent | Number | Percent | Number | Percent | | Number | Percent | Number | Percent |
| Faust | 44 | 22.11 | 4 | 9.09 | 19 | 12.25 | 39 | 5 | 12.81 | 24 | 16.66 |
| Gulliver's Travels | 51 | 25.62 | 11 | 21.56 | 38 | 25.67 | 34 | 22 | 64.70 | 82 | <55.03 |
| Origin of Species | 86 | 43.21 | 18 | 20.93 | 22 | <19.46 | 80 | 34 | 42.50 | 54 | 52.42 |
| Ancient Mariner | 95 | 47.73 | 24 | 25.26 | 31 | 29.80 | 89 | 29 | 32.58 | 54 | 57.44 |
| Les Miserables | 96 | 48.24 | 12 | 12.50 | 19 | 18.43 | 88 | 35 | 39.77 | 36 | <37.89 |
| The Raven | 126 | 63.31 | 24 | 19.04 | 9 | <12.33 | 118 | 61 | 51.69 | 39 | 60.00 |
| Snow Bound | 128 | 64.32 | 27 | 21.09 | 22 | 30.98 | 118 | 62 | 52.54 | 39 | 60.00 |
| Pilgrim's Progress | 135 | 67.83 | 44 | 32.59 | 27 | 42.18 | 124 | 68 | 54.83 | 42 | 71.81 |
| Treasure Island | 146 | 73.36 | 43 | 29.45 | 18 | 33.96 | 135 | 66 | 48.88 | 28 | 58.33 |
| Lady of the Lake | 156 | 78.39 | 34 | 21.79 | 11 | 25.58 | 146 | 64 | 43.83 | 14 | <37.83 |
| David Copperfield | 156 | 78.39 | 37 | 23.71 | 6 | <13.95 | 148 | 58 | 39.18 | 11 | <31.42 |
| Paradise Lost | 161 | 80.90 | 29 | 18.01 | 18 | 47.36 | 147 | 64 | 34.53 | 22 | 61.11 |
| The Iliad | 173 | 86.93 | 26 | 15.02 | 7 | 26.92 | 164 | 69 | 42.07 | 12 | 63.15 |
| Hiawatha | 182 | 91.46 | 45 | 24.72 | 13 | 76.47 | 168 | 99 | 58.92 | 11 | 73.33 |
| Hamlet | 193 | 96.98 | 30 | 15.54 | 5 | 83.33 | 179 | 74 | 41.34 | 4 | 100.00 |
| Arith. Mean | 128.43 | | | 20.68 | | 33.24 | 118.47 | | 44.61 | | 55.76 |

To be read: Of 199 students 44 or 22.11 percent knew that Goethe wrote Faust.
Of 44 students who knew author of Faust, 4 or 9.09 percent did not recall the false author, Homer.
Of 155 students not knowing author of Faust, 19 or 12.25 percent did not recall the false author, Homer. (See page 277.)

To be read as same as Immediate Recall.

## TABLE VII

INHIBITIONS TO FALSE AUTHORS IN LESS KNOWN LITERATURE

| Books | Total Known | | I. Immediate Recall (180 Subjects) Unrecalled *False* Authors, when *True* Authors are: | | | | Total Number Known | II. Delayed Recall (159 Subjects) Unrecalled *False* Authors, when *True* Authors are: | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *a.* Known | | *b.* Unknown | | | *a.* Known | | *b.* Unknown | |
| | No. | Percent | Number | Percent | Number | Percent | | Number | Percent | Number | Percent |
| The Excursion | 9 | 4.97 | 1 | 11.11 | 31 | 18.02 | 8 | 4 | 50.00 | 75 | <49.66 |
| The Ring and the Book | 9 | 4.97 | 2 | 22.22 | 30 | <17.44 | 13 | 3 | 23.76 | 73 | 50.00 |
| The Man with the Hoe | 19 | 10.49 | 1 | 5.26 | 28 | 17.27 | 10 | 5 | 50.00 | 60 | <40.26 |
| Rasselas | 19 | 10.49 | 5 | 26.31 | 41 | <23.29 | 17 | 9 | 52.94 | 104 | 73.23 |
| Modern Painters | 25 | 13.81 | 0 | 00.00 | 6 | 38.46 | 23 | 4 | 17.39 | 26 | 19.11 |
| She Stoops to Conquer | 36 | 19.88 | 4 | 11.11 | 32 | 22.06 | 42 | 8 | 19.04 | 59 | 50.42 |
| The Skylark | 42 | 23.20 | 5 | 11.90 | 22 | 15.82 | 36 | 20 | 55.55 | 58 | <47.15 |
| Tam O'Shanter | 44 | 24.30 | 6 | 13.63 | 42 | 30.65 | 39 | 22 | 56.41 | 66 | <55.00 |
| Vision of Sir Launfal | 71 | 39.23 | 13 | 18.30 | 29 | 26.36 | 61 | 36 | 59.01 | 48 | <48.79 |
| The Scarlet Letter | 81 | 44.75 | 20 | 24.69 | 25 | 25.00 | 70 | 52 | 74.28 | 45 | <51.86 |
| Vanity Fair | 91 | 50.27 | 24 | 25.38 | 14 | <15.55 | 72 | 44 | 61.11 | 30 | <34.48 |
| The Inferno | 106 | 58.56 | 16 | 15.09 | 19 | 25.33 | 93 | 50 | 53.76 | 38 | 57.57 |
| The Jungle Book | 113 | 62.98 | 27 | 23.89 | 17 | 25.00 | 102 | 65 | 63.72 | 33 | <57.89 |
| Sleepy Hollow | 119 | 65.74 | 18 | 11.12 | 11 | 17.74 | 89 | 42 | 47.19 | 23 | <32.85 |
| Uncle Tom's Cabin | 142 | 78.42 | 26 | 18.30 | 2 | < 5.12 | 124 | 74 | 59.61 | 12 | <48.00 |
| Arith. Mean | 61.73 | | | 17.88 | | 21.54 | 53.27 | | 49.58 | | 47.55 |

To be read as Table VI.

are comparable in inhibiting force to the apparently unknown capitals. In other words, unknown capitals were really less known, and as such offered more inhibition than known. And, further, unknown authors in L.K. Lit. exert, apparently, a minimum of opposition, that is, they are approaching the condition of the unknown authors of the check material. According to this, the least known of the less known authors exert an inhibition similar to the best known of the well-known authors, *i.e.*, the extremes meet, so far as the inhibiting power is concerned, both are approaching the condition of the check material!

It appeared that a further analysis of the results might be made at this point by arranging the authors of the W.K. and L.K. Lit., in an array according to the number of authors known and then determining the amount of inhibiting of the individual authors.

The results of such an array and the computations made are expressed in Tables VI. and VII. The array of Table VI., while offering nothing new, confirms in a striking way the gross results already described. The arithmetical mean shows: (1) That inhibition is less in immediate than in delayed recall, (2) that the percentage of the unrecalled false authors is greater when the true author is unknown. But the arithmetical mean in delayed recall in Table VII., L.K. Lit., shows a reversal of that relation; *the inhibition of the known is greater than the inhibition of the unknown.* The arithmetical mean of the former is 49.58, and of the latter 47.55. The small difference between these two means is due to excessive variations in the 'unknown' column. The extent of the reversal is seen to a better advantage by comparing the percentages of the same author in the known and unknown columns. To aid in this the mathematical sign for 'less than' appears before those percentages in the unknown column that are less, respectively, than those in the known column. Ten of the fifteen authors have these signs in the unknown column of delayed recall in L.K. Lit. In a similar column of Table VI. four such signs appear.

To get another view of the relation between the degrees of

knowledge and inhibition, the literary works of both W.K. and L.K. Lit. were arranged together in an array of thirty, according as their authors were known. The averages of the percentages of the first and fourth quartiles respectively and of the middle half of the percentages of the unrecalled false authors in both known and unknown columns were computed. These averages are as follows:

| First quartile | Middle half | Fourth quartile |
|---|---|---|
| Known.....33.83% | Known.....53.77% | Known.....47.05% |
| Unknown.....43.06% | Unknown.....52.38% | Unknown.....59.20% |

The first quartile of the known column, containing seven and one half literary works is composed of L.K. Lit. except Faust. The authors of this quartile were least known, and it had the fewest unrecalled false authors, 33.83 percent. The middle half, composed of 14 whole and two half works, or a total of 15, had an equal number of W.K. and L.K. Lit. There is an average of 53.77 percent of unrecalled false authors. The fourth quartile, having all W.K. Lit., except Uncle Tom's Cabin, has an average of 47.05 percent. The same quartile in the unknown column, containing the best known authors, has the highest percentage of unrecalled, 59.20 percent.

This quartile analysis of the percentages of the unrecalled false authors shows at least five sets of facts:

1. The least known of the L.K. Lit. offers no inhibition, but rather favors learning. The student had merely heard the names of the works, and that fact favored their association with even a false author (33.83 percent).

2. The entirely unknown of the L.K. Lit. (from the learners' standpoint) neither favors nor hinders learning; its status is neutral, and therefore comparable to that of new material. The percentage of the unrecalled is 43.06 percent, and this is very close to the percentage, 44.70 percent of the unrecalled true authors of the check material, Table IV.

3. The known authors of the L.K. Lit. and the unknown authors of the W.K. Lit. (middle half) offer decided opposition to making new associations (53.07 percent).

## TABLE VIII

SHOWING RESULTS OF REACTION TIME TO TRUE AND FALSE ASSOCIATIONS IN GEOGRAPHY AND IN ARITHMETIC

| Subjects | | True Capitals | False Association: Capitals | | True Associations County Seats | | True Associations Sums of Numbers | False Associations Sums of Numbers | | Association Sums of Letters | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ser. I. | Ser. II. | Ser. I. | Ser. II. | | Ser. V. | Ser. VI. | Ser. V. | Ser. VI. |
| | Mean | 1.342 | 1.849 | | 1.392 | | 1.700 | 2.408 | 2.893 | 2.056 | 1.972 |
| | Range | 1.788 | 2.636 | | 2.228 | | 1.120 | 2.664 | 4.812 | 2.468 | 2.800 |
| *L.* | P. E. | .0370 | .0680 | | .0463 | | .1632 | .1037 | .1915 | .0106 | .0887 |
| | Mean | 1.580 | 8.860 | 5.312 | 5.730 | 1.412 | 1.585 | 3.370 | 3.392 | 2.293 | 4.560 |
| | Range | 2.472 | 9.536 | 18.728 | 10.448 | 1.576 | 2.968 | 11.252 | 2.340 | 6.384 | 8.800 |
| *M.* | P. E. | .0511 | .5736 | 1.1780 | .0290 | .0327 | .0437 | .3361 | .1166 | .1715 | .2338 |
| | Mean | 1.712 | 2.060 | 1.928 | 1.520 | 1.904 | | 3.000 | 5.164 | 5.288 | 2.236 |
| | Range | 2.940 | 26.324 | 10.484 | 1.832 | 1.940 | | 3.312 | 13.180 | 25.748 | 2.376 |
| *R. H.* | P. E. | .0490 | .0867 | .2537 | .0470 | .0512 | | .1087 | .0434 | .0793 | .0900 |
| | Mean | 1.692 | 3.300 | 3.924 | 4.512 | 1.568 | 1.464 | 4.776 | 3.804 | 1.912 | 3.456 |
| | Range | 3.164 | 8.620 | 5.126 | 4.236 | 0.248 | .740 | 12.656 | 3.008 | 2.696 | 4.784 |
| *B.* | P. E. | .0666 | .0227 | .0926 | .1982 | .0585 | .0199 | .0458 | .1900 | .0830 | .1619 |
| | Mean | 1.280 | 2.550 | 2.088 | 1.848 | 3.704 | 1.300 | 2.372 | 2.544 | 3.140 | 2.696 |
| | Range | 2.080 | 4.388 | 2.932 | 1.224 | 11.764 | 1.503 | 3.516 | 2.460 | 5.780 | 2.944 |
| *W.* | P. E. | .0565 | .1933 | .1339 | .0571 | .2433 | .0269 | .1038 | .0999 | .2350 | .1304 |
| | Mean | 2.316 | 5.012 | 2.228 | 6.908 | 1.328 | 1.628 | 6.448 | 5.864 | 2.300 | 2.744 |
| | Range | 5.276 | 7.652 | 4.132 | 9.120 | 2.116 | 1.516 | 7.268 | 16.744 | 1.876 | 2.096 |
| *C.* | P. E. | .0301 | .2591 | .0919 | .0770 | .0489 | .0255 | .0588 | .0519 | .1133 | .0722 |
| | Mean | 1.232 | 5.032 | | 1.516 | | | 2.764 | 3.040 | 1.604 | 1.980 |
| | Range | 2.924 | 27.324 | | 2.752 | | | 5.840 | 2.964 | 1.864 | 2.256 |
| *E. H.* | P. E. | .0348 | .0665 | | .0710 | | | .1266 | .0955 | .0573 | .0912 |
| Mean of total: | | | | | | | | | | | |
| | Means | 1.593 | 4.095 | 3.096 | 3.346 | 1.983 | 1.535 | 3.591 | 3.814 | 2.656 | 2.806 |
| | Ranges | 2.949 | 12.350 | 8.298 | 4.548 | 3.528 | 1.569 | 8.072 | 6.501 | 6.688 | 3.722 |
| | P. E.'s | .0464 | .1813 | .3500 | .0750 | .0865 | .0558 | .1287 | .1126 | .1071 | .1240 |

4. The unknown of the best known (fourth quartile) of W.K. Lit. offers a maximum of inhibition (59.20 percent).

5. The known of the best known of W.K. Lit. offers comparatively little inhibition, if we measure it by the difference between the percentage of unrecalled false authors, 47.05 percent, and the unrecalled authors of the check series 44.70 percent, a difference of only 2.33 percent.

### *B. Procedure with Individual Subjects*

Twelve subjects were used, seven with the false geography, and seven with the false authors, two serving in both. Four of the geography group were college graduates, two of whom were psychologists. The remaining four were undergraduates and had not studied psychology. *L* and *C* (Table VIII.) knew the purpose of the experiment.

(*a*) The same geography material used in the group experiment was used here. The subject's current knowledge of the captials and familiarity with the states used in the experiment were first ascertained. Then his normal constrained association time for giving true capitals of states was determined by the Johns Hopkins chronoscope. Twenty states were used for this purpose and also twenty foreign countries. While the current knowledge of foreign capitals was much higher than that of the states, the association reactions showed 400$^{\sigma}$ shorter for the states.

To subjects unfamiliar with making verbal responses to a chronoscope, preliminary practice was given. A period of 45 minutes or more was required for learning both the false and check material. The learning time was 15 minutes each for the capitals and the county seats, with an interval of 10 minutes between. Immediate recall was made in both cases by writing as the name of state or county was pronounced. The pronouncing order was different from the learning order. After an interval of 48 hours both series were reviewed, five minutes being devoted to each. At the end of the ten minutes review the subjects' reaction time was determined by the chronoscope. The names of the states and of the counties were pronounced by the experimenter in an irregular order,

the subject responding verbally to each with the name of its appropriate false capital or county seat as the case might be. The Johns Hopkins chronoscope made it possible to get constrained association time readily and free from distractions. Two sets of countries were used, Series I., European, and Series II., States of the Union. Sample reaction times are shown here in Series I. and Series II.

SERIES I. *Groups (a) and (b) Combined for Comparison*

| Country and County Alternating | Capital or County Seat | Reaction Time |
|---|---|---|
| Italy | Lisbon | 554 |
| Chester | Henderson | 696 |
| Germany | Stockholm | 245 |
| Lamar | Vernon | 270 |
| Spain | Warsaw | 605 |
| Early | Blakeley | 639 |
| Turkey | Madrid | 608 |
| Meigs | Pomeroy | 392 |
| Austria | Brussels | 236 |
| Tomba | Lyons | 358 |
| France | Tokio | 496 |
| Bradford | Stock | 518 |
| Poland | Rio de Janeiro | 656 |
| Hernando | Ingham | 443 |
| Brazil | Paris | 395 |
| Turner | Ashburn | 378 |
| Japan | Edinburgh | 276 |
| Franklin | Yeager | 625 |
| Ireland | Berne | 530 |
| Hardeman | Bolivar | 530 |
| England | Mexico City | 508 |
| Bond | Greeneville | 750 |
| Switzerland | London | * |
| Gadsden | Quincy | 267 |
| Belgium | Vienna | 2620 |
| Terrill | Dawson | 323 |
| Portugal | Berlin | 375 |
| Obion | Union City | 814 |
| Mexico | Dublin | 288 |
| Kanabec | Morrow | * |

| Capitals | County Seat |
|---|---|
| Average = 513.7$^{\sigma}$ | 500$^{\sigma}$ |
| Median = 502. | 481 |

SERIES II. *Arranged for Testing*

| State and County Alternating | Capital or County Seat | Reaction Time |
|---|---|---|
| Pike | Magnolia | 380 |
| Virginia | Montgomery | 1429 |
| Copiah | Hazelhurst | 238 |
| Idaho | Little Rock | 275 |
| Pearl | Poplarville | 114 |
| Kentucky | Madison | 488 |
| Webster | Walthall | 297 |
| Nebraska | Richmond | 372 |
| Wilcox | Camden | 575 |
| Tennessee | Sacramento | 148 |
| Alcorn | Corinth | 430 |
| Rhode Island | Denver | 466 |
| Barbour | Clayton | 362 |
| Georgia | Tallahassee | 1033 |
| Quitman | Belan | 263 |
| Wisconsin | Indianapolis | 370 |
| Sharkey | Rolling-Fork | 497 |
| Indiana | Prescott | 785 |
| Tate | Senatobia | 437 |
| California | Springfield | 333 |
| Benton | Ashland | 619 |
| Arizona | Dover | 154 |
| Tippah | Ripley | 176 |
| South Carolina | Hartford | 1124 |
| Leflore | Greenwood | 271 |
| Missouri | Montpelier | 370 |
| Homes | Lexington | 238 |
| New Hampshire | Olympia | 312 |
| Hinds | Raymond | 90 |
| New Jersey | Charleston | 125 |

| Capitals | County Seat |
|---|---|
| Average = 568.9$^{\sigma}$ | 332$^{\sigma}$ |
| Median = 370. | 271$^{\sigma}$ |

*No record taken.

The combined results are given in Table VIII. Series II., composed of states, was regarded by the subjects as more difficult, but the general average of the association times is shorter than that of Series I., requiring false capitals for European countries. Usually the difference might be attributed to practice, and for some of the subjects that appears to be the case. *W* and *R. H.* learned Series I. first, and had a shorter association time than Series II. *M*, *B*, and *C*, learned Series II. first, and here practice effects appeared only with *B*. That is, practice effects are evident in three, and not apparent in two cases. With two subjects, *B* and *C*, the time of reaction in one of the check series is longer. They attribute it to the confusion arising from the names of certain county seats ending in 'ville.' In all other instances a shorter time was registered.

The manner of learning in both the test and check series followed the same lines. (1) Mnemonic devices where employed followed the same lines, *e.g.*, Kentucky-Mad-i-son. "Kentucky makes whiskey, whiskey makes madison." (2) Ingenious intermediaries were resorted to. (3) 'Straight-memory' as termed by the subject.

(*b*) *The Association of False Sums of Numbers.*—In general the procedure with this method followed that observed with the false capitals. Each series had only ten pairs, as given here.

| Series V | Series VI | Check Series V |
|---|---|---|
| 2 + 2 = 13 | 10 + 13 = 27 | *L* + *P* = 8 |
| 1 + 3 = 2 | 9 + 14 = 20 | *R* + *O* = 7 |
| 3 + 7 = 12 | 7 + 15 = 43 | *G* + *M* = 12 |
| 4 + 5 = 7 | 11 + 12 = 19 | *N* + *K* = 11 |
| 6 + 2 = 9 | 13 + 16 = 30 | *Q* + *L* = 17 |
| 5 + 3 = 6 | 8 + 17 = 22 | *B* + *E* = 13 |
| 8 + 3 = 23 | 12 + 14 = 28 | *O* + *V* = 14 |
| 4 + 2 = 5 | 14 + 8 = 18 | *K* + *R* = 19 |
| 2 + 7 = 15 | 6 + 9 = 16 | *T* + *J* = 16 |
| 8 + 4 = 10 | 15 + 6 = 17 | *D* + *C* = 21 |

Ten minutes were devoted to learning. Immediate recall was done by both writing and pronouncing the false or arbi-